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Decoupling Control of Electro-Pneumatic Pressure Tank System

A. Sompol, S. Chitwong, and P. Nilas

***Abstract*—This paper presents pressure and flow control by using nonlinear PI decoupling control structure for the two-input and two-output pressure tank system at which electro-pneumatic proportional pressure and flow valves are employed as both actuators together with pressure and flow sensor. Experimental results are evaluated in three conditions. First, a fixed pressure value is set and flow value is varied as step. Second, a fixed flow value is set while varying pressure value. Final, both pressure and flow value is simultaneously varied. All results show good control performance by which both pressure and flow rate can reach to set point in all condition.**

***Index Terms*—Pressure tank system, Nonlinear PID controller, Decoupling control, Neural network with turning and decoupling, Electro-pneumatic proportional pressure and flow value.**

I. Introduction

Generally the simple electro-pneumatic controller for one actuator is proportional, integral and derivative algorithm used for single-input and single-output control system [4] at which it is easy to implementing and tuning. But a real process control in industrial using actuator more than one is very complex, implementation of multi-input and multi-output (MIMO) or multi-variable control system is then necessary. A number of control forms are used such as cascade control, ratio control, feed-forward control and decoupling control, and etc [5]. Pressure tank system which has been used two control valves as actuator for both pressure and flow rate was in the form as two-input and two output (TITO) adaptive decoupling control system [3]. In controlling pressure tank system by employing electro -pneumatic actuator at which the electro-pneumatic proportional pressure and flow valve is applied to control pressure in chamber and flow rate, respectively. Normally, since characteristic of electro-pneumatic actuator is nonlinear, so the electro-pneumatic based TITO system is time-varying and decoupling. The nonlinear PID controller [1] and neural decoupler [2] are combined and adapted to construct the electro-pneumatic pressure tank system. For our set up system is not addressing disturbance. The parameters of the implemented control system are adaptively tuned online to cover operating point.

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A. Sompol, S. Chitwong, and P. Nilas are with the Department of Instrumentation Engineering, Faculty of Engineering,King Mongkut's Institute of Technology Ladkrabang, Ladkrabang, Bangkok 10520 THAILAND. (e-mail: {kcsakrey, knphongc }@kmitl.ac.th).

This paper is organized as follows. In section II, overview detail of the system description is described for setting up system to evaluate. The control system comprises of nonlinear PID controller, neural decoupler and decoupling control structure described briefly in Section III. Experimental results and conclusions are shown and discussed in Section IV and V, respectively.

II. System Description

The general overview of the electro-pneumatic pressure tank system is shown in Fig. 1. The one consists of three parts (1) air supply prepared pressure of 7.5 bars, (2) electro-pneumatic pressure tank system, and (3) personal computer (PC) with the data acquisition board. The electro-pneumatic pressure tank system comprises of (a) chamber, (b) pressure sensor (SUNX, DP2-22) which is used to measure the pressure in chamber, (c) flow sensor (SIERRA, 822S-M-2-OV1-PV1-V1) to measure the flow rate, (d) the electro-pneumatic proportional pressure and flow valve (SMC, VEP3121-1 for pressure and VEF2121-1 for flow) together with amplifier (SMC, VA250). For pressure sensor, the output voltage as analog pressure signal, 1-5V rescaled into 0-5V corresponding to 0-1 MPa or 0-10 bars, from the pressure sensor is converted into the digital data in PC via a data acquisition board (NI, PCI-6024E) as analog to digital converter (ADC). For flow sensor, the output voltage as analog flow signal, 0-5V corresponding to 0-100 liters per minute (l/m), from the flow sensor is converted into digital data the same as the analog pressure signal.

A control signal, both analog pressure and flow signal, computed within PC will generate each of 0-5 V, by using the data acquisition board as digital to analog converter (DAC) used to drive the pneumatic pressure tank system actuators which are the electro-pneumatic proportional pressure and flow valves. Since the electro-pneumatic proportional value must be driven by current, voltage to current converter as amplifier is then employed to convert control signal as voltage (0-5V) into current (0-1A). In our case, the minimum and maximum output pressure is controlled in range 1.5-2.5 bars and the minimum and maximum output flow rate is controlled in range 20-60 l/m.

The pressure characteristic between input current and output pressure and the flow characteristic between input current and effective area corresponding with flow rate can see from SMC website [http://www.smcworld.com].

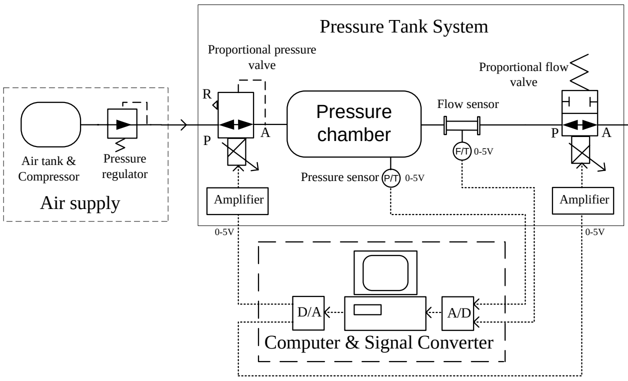

Fig. 1 Electro-pneumatic pressure tank system

III. CONTROL SYSTEM

A. Nonlinear PID Controller

The well-know controller structure which is popularly implemented for industrial process control is proportional, integral, derivative (PID) control because it is sample, robust and stable. Important key of employing PID control is optimal parameter consisted of proportional, integral and derivative gain. Normal, applying PID control for nonlinear and time-varying process control was as fixed parameters caused to low performance controller. A way to improve performance of controller is online adjusting such parameters optimally and employing nonlinear controller. In this paper, we employ nonlinear PID controller [1] shown in Fig. 2 which will be briefly described as following.

A control signal u is obtained by using the sigmoid function as equ. (1).

$$u = f(x) = \frac{2(1-e^{-xY_g})}{Y_g(1+e^{-xY_g})} \tag{1}$$

where

x is the input variable of sigmoid function $f(\bullet)$,

Y_g is the parameter to determine the shape of sigmoid function.

The input variable of the sigmoid function got from PID controller is as equ. (2)

$$x(k) = K_p(k)e_p(k) + K_i(k)e_i(k) + K_d(k)e_d(k) \tag{2}$$

where

$K_p(k)$, $K_i(k)$, and $K_d(k)$ is proportional, integral, derivative gain, respectively,

$e_p(k) = r(k) - v(k)$ is error value between desired set point and process variable ,

$e_i(k) = \sum_{n=1}^{k} e_p(n)\Delta T$ is integral of error by which ΔT is the sampling time and k the discrete sequence,

$e_d(k) = \frac{e_p(k)(1-z^{-1})}{\Delta T}$ is difference of error by which z is the Z-transform operator.

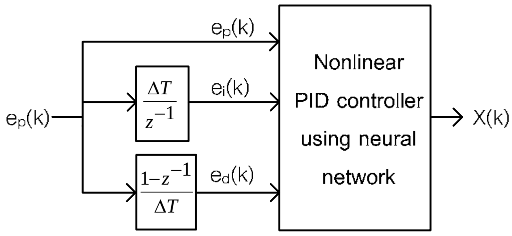

Fig. 2 Structure of nonlinear PID Controller.

To obtain optimally nonlinear PID parameter, equ. (3) is used to tuning of them.

$$\begin{aligned} K_p(k+1) &= K_p(k) + n_p e_p(k) e_p(k) f'(x) \\ K_i(k+1) &= K_i(k) + n_i e_p(k) e_i(k) f'(x) \\ K_d(k+1) &= K_d(k) + n_d e_p(k) e_d(k) f'(x) \end{aligned} \tag{3}$$

where

$f'(x) = \frac{4(1-e^{-xY_g})}{(1+e^{-xY_g})^2}$. is the derivative of sigmoid function,

η_p, η_i, and η_d are learning rates.

B. Neural Decoupler

The pressure tank system is process consisted of pressure and flow controlling part, that is, one is a two-input and two-output (TITO) process. Also it is strong decoupling between pressure and flow rate variables. One technique popularly employed to solve decoupling effect is inserting a decoupler between controller and process. In this paper, neural network consisted of delay time links (TDL) and a three-layer neural network in the input, hidden and output layer, respectively is applied as the two-input and two-output decoupler, namely the neural decoupler [2]. The control signals for both pressure and flow, $u_p(k)$ and $u_f(k)$, respectively are the outputs of decoupler written as equ. (4a) and (4b).

$$\begin{aligned} u_p(k) = F_1(&x_p(k), x_p(k-1), \cdots, x_p(k-n_1); \\ &x_f(k), x_f(k-1), \cdots, x_f(k-n_2); \\ &u_p(k), u_p(k-1), \cdots, u_p(k-m_1); \\ &u_f(k), u_f(k-1), \cdots, u_f(k-m_2)) \end{aligned} \tag{4a}$$

$$\begin{aligned} u_f(k) = F_2(&x_p(k), x_p(k-1), \cdots, x_p(k-n_1); \\ &x_f(k), x_f(k-1), \cdots, x_f(k-n_2); \\ &u_p(k), u_p(k-1), \cdots, u_p(k-m_1); \\ &u_f(k), u_f(k-1), \cdots, u_f(k-m_2)) \end{aligned} \tag{4b}$$

where k is the discrete-time, m_1, m_2, n_1 and n_2 are non-negative integers.

If let all of them be of 7, the number of neurons in the input layer is then of 28. For TITO process, neurons of the output layer are of 2. Also the number of neurons in the hidden is of 4.

Error functions, J_1 and J_2, for training neural decoupler are as equ. (5)

$$J_1 = \frac{1}{2}\sum_{k=0}^{n}(v_p(k) - v_{pd}(k))^2 \quad (5a)$$

$$J_2 = \frac{1}{2}\sum_{k=0}^{n}(v_f(k) - v_{fd}(k))^2 \quad (5b)$$

where

$v_p(k)$, $v_f(k)$ are process variables for pressure and flow rate, respectively,

$v_{pd}(k)$ and $v_{fd}(k)$ are process variables for conditioned pressure and flow rate, respectively corresponding with the output signal of each controller.

The training procedures of neural decoupler to minimize the error function are as following.

Step 1 Apply the output signal of pressure controller $x_p(k)$ as step input signal corresponding with the conditioned process variable $v_{pd}(k)$ and let $x_f(k)$ be zero, the conditioned process variable $v_{fd}(k)$ should be zero.

Step 2 Similar, Apply the output signal of flow controller $x_f(k)$ as step input signal corresponding with the conditioned process variable $v_{fd}(k)$. Let $x_p(k)$ be zero, the conditioned process variable $v_{pd}(k)$ is zero.

Step 3 Apply both the output signal of pressure and flow controller $x_p(k)$ and $x_f(k)$ simultaneously corresponding with the conditioned process variable $v_{pd}(k)$ and $v_{fd}(k)$, respectively.

Each step is trained independently as the back-propagation algorithm to reduce the error functions.

Step 4 Perform iteratively step 1 to step 3, until the error is low enough or the number of iterations is of a desired number.

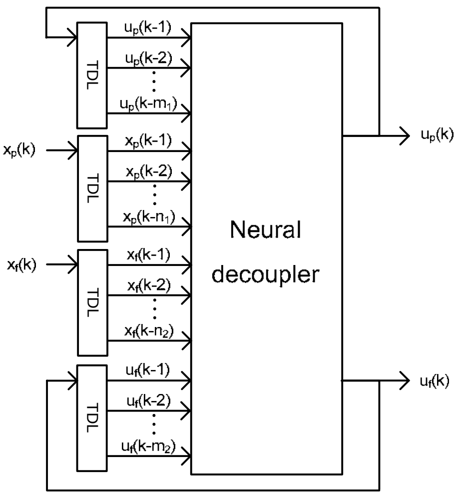

Fig. 3 Neural decoupler.

C. Decoupling Control Structure

To obtain the nonlinear PID decoupling control system, controller consisted of pressure and flow controller at which parameter of both ones is individually tuned online, the TITO neural decoupler and electro-pneumatic pressure tank system as TITO process are combined as shown in Fig. 4.

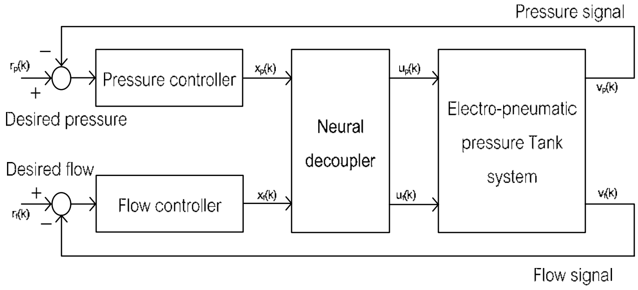

Fig. 4 The nonlinear PID decoupling control system.

IV. EXPERIMENTAL RESULTS

Experimental tests were carried out to evaluate the proposed control method by utilizing the Matlab/Simulink program. The sampling time is of 1 ms. For electro-pneumatic pressure tank system, two PI controllers with neural network for tuning and decoupling are implemented. A number of training pattern for decoupler are of 500 being generated in range 0-3 bars for pressure and 0-80 l/m for flow rate by pseudo-random function. The initial parameters of PI controller were obtained by trial-and-error with random and tuned to improve performance of controller.

By using our setup system shown in Fig. 1, Fig. 5 shows the experimental results with three conditions. First the fixed set point of pressure is of 2.5 bars and varying flow rate from 20 to 60 l/m is at time of 5 second. Seeing in Fig. 5(a) shows that at time of 5 second the pressure is not only decreased little because of increased flow rate and back to the set point again, but also the flow rate can precisely reach to the set point. Second the fixed set point of flow rate is of 60 l/m and varying pressure from 1.5 to 2.5 bars is at time of 2 second. Seeing in Fig. 5(b) shows that at time of 2 second the pressure can reach to the set point, but flow rate is increased because of increased pressure and back to the set point again. Final varying pressure and flow rate is from 1.5 to 2.5 bars at time of 2 second and 20 to 60 l/m at time of 7 second, respectively. Result of performance of controller shown in Fig. 5(c) is the same as previous two conditions.

V. CONCLUSION

Because pneumatic pressure tank system using electro-pneumatic proportional pressure and flow valve as actuator at which such system shows nonlinear, time-varying and strong decoupling, performance of system is then degraded for the conventional PI controller with a fixed parameter. To solve such problem, the nonlinear PI controller with neural network is not only applied to handle a nonlinearity and time-varying system by adapting control parameters online but also decoupling method as neural decoupler is inserted between controller and process to improve the decoupling effect. By the proposed method, the number of responses of system can reach to set point precisely and fast enough.

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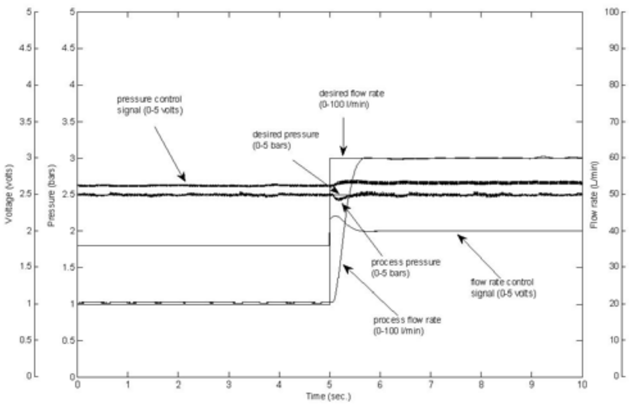
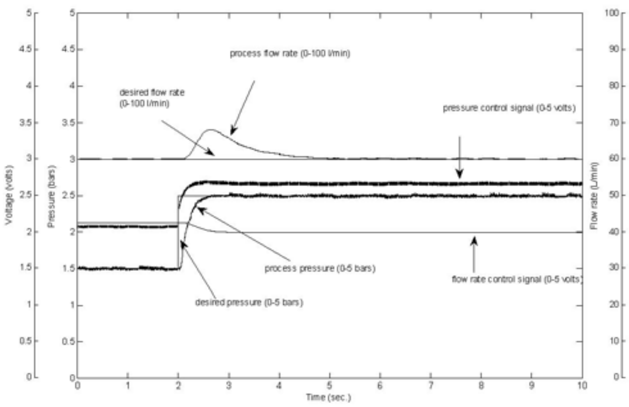
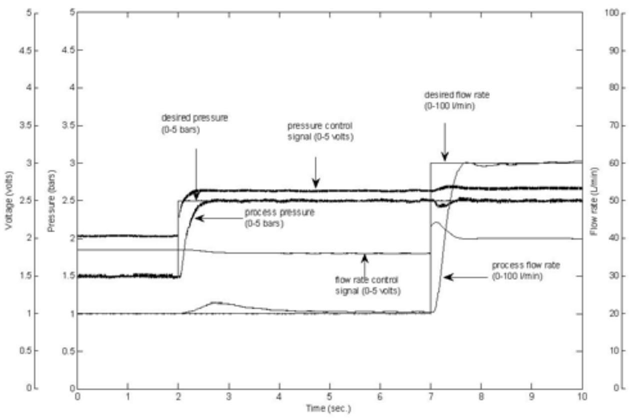


(a)



(b)



(c)

Fig. 5 Experimental results (a) the fixed pressure value, varying flow rate (b) fixed flow value, varying flow rate (c) varying pressure and flow rate